Faculty of Manufacturing Engineering

OPTIMIZATION OF DRILL GEOMETRY DESIGN FOR ORTHOPAEDIC SURGICAL APPLICATION IN DRY DRILLING CONDITION

Ir. Noorazizi bin Mohd Samsuddin

Doctor of Philosophy in Manufacturing Engineering

2017

OPTIMIZATION OF DRILL GEOMETRY DESIGN FOR ORTHOPAEDIC SURGICAL APPLICATION IN DRY DRILLING CONDITION

IR. NOORAZIZI BIN MOHD SAMSUDDIN

A thesis submitted
in fulfillment of the requirements for the degree of Doctor of Philosophy

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2017

DECLARATION

I declare that this thesis entitled “Optimization of Drill Geometry Design for Orthopaedic Surgical Application in Dry Drilling Condition” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

Signature : ……

Name : Ir. Noorazizi B. Mohd Samsuddin

Date : ……..

APPROVAL

I hereby declare that I have read this dissertation/report and in my opinion this dissertation/report is sufficient in terms of scope and quality as a partial fulfillment of Doctor of Philosophy in Manufacturing Engineering.

Signature : ……

Name : Assoc.Prof. Dr Raja Izamshah Raja Abdullah

Date : ……..

DEDICATION

To my beloved wife, daughters, and sons

ABSTRACT

During a routine orthopedic surgery, the principle biomechanical procedure in repairing and reconstructing bone fractures is done by drilling the bone, fixing and re-attaching the separate parts using screws, wires, and plates. Such a procedure is usually performed manually with a hand-held surgical tool. Hitherto, the rate of success of these surgeries varies significantly and often highly dependent on the surgeons' skills. Medical tool designers have always neglected this important factor in their designs. Common scenarios of imprecise manipulations or deviations from normal drill axis can cause the drill to skid across the bone surface. These maladjustments affect the hole accuracy, which then leads to a localized temperature rise resulting in thermal necrosis of the soft tissues surrounding the hole region. Many different surgical drill bit designs and geometries have been proposed over the years, each with its own claim of success. However, most of the drills are based on normal 0 degree penetration angle which does not represent the realistic angle of manually controlled penetrations by surgeons. In drilling mechanics, a deviation of 1 degree of penetration angle from the normal bone surface will result in frictions increment which then would antagonize the hole performance. Recognizing the importance of studying this phenomenon, this research develops a new surgical drill bit design to solve the discrepancies during orthopedic surgeries. The development of the new drill design is achieved through the combination of the in-vitro experimental work and statistical optimization technique. A total of 17 different drill designs with varied helix angle, point angle, and web thickness were fabricated and tested on drilling bovine femur cortical bone at different penetration angles. The effects of each factor on the hole accuracy, surface roughness, drilling force and drilling temperature were considered as the desired response that needs to be achieved for the new drill design. From the investigation, the most significant parameter that affects the hole performance was the penetration angle followed by the point angle. Also, the interaction between helix angle and web thickness controlled the drilling performance. Through statistical optimization analysis, the selected optimum drill geometry angles that score the highest desirability based on 30° penetration angle condition was (25% web thickness, 107.0° point angle, and 35.0° helix angle). The new optimum drill design was fabricated and followed by a set of validating experimental works that produced less than 10% error which confirms its validity. The proposition of a new geometric design for surgical drill bits that takes into account of up to 30° drilling penetration angle deviations will further catalyze breakthrough advancements in biomechanical and biomedical technologies.

ABSTRAK

Semasa rutin pembedahan ortopedik, prosedur prinsip biomekanik dalam membaiki dan membina semula keretakan tulang dilakukan dengan penggerudian, menetapkan dan melampirkan semula bahagian yang berasingan menggunakan skru, wayar dan plat. Prosedur ini biasanya dilakukan secara manual dengan menggunakan alat pembedahan tangan. Sehingga kini, kadar kejayaan pembedahan rendah dengan ketara dan sangat bergantung kepada kemahiran pakar bedah. Pereka alat pembedahan sentiasa mengabaikan faktor penting ini dalam reka bentuk mereka. Senario biasa yang berlaku iaitu manipulasi tidak tepat atau penyelewengan dari paksi gerudi normal boleh menyebabkan gerudi tergelincir di seluruh permukaan tulang. Ini menjejaskan ketepatan lubang, yang membawa kepada kenaikan suhu setempat menyebabkan nekrosis haba tisu lembut berlaku di sekitar kawasan lubang. Banyak gerudi bit pembedahan dengan reka bentuk dan geometri yang berbeza telah dicadangkan selama ini, masing-masing dengan tuntutan sendiri untuk berjaya. Walau bagaimanapun, kebanyakan rekabentuk adalah berdasarkan pada 0 darjah sudut penembusan biasa yang tidak mewakili sudut yang realistik penembusan sepertimana yang dikawal secara manual oleh pakar bedah. Dalam mekanik penggerudian, sisihan daripada 1 darjah sudut penembusan dari permukaan tulang normal akan menyebabkan peningkatan geseran yang kemudiannya akan menjejaskan prestasi lubang. Menyedari kepentingan fenomena ini, kajian ini membangunkan reka bentuk pembedahan bit gerudi baru untuk menyelesaikan percanggahan semasa pembedahan ortopedik. Pembangunan reka bentuk bit gerudi baru dapat dicapai melalui gabungan kerja-kerja eksperimen dan statistik teknik pengoptimuman. Sebanyak 17 reka bentuk bit gerudi yang berbeza telah direka pada sudut helix, sudut mata, ketebalan web dan diuji pada penggerudian tulang lembu kortikal paha pada sudut penembusan yang berlainan. Kesan daripada setiap faktor iaitu ketepatan lubang, kekasaran permukaan, daya penggerudian dan suhu penggerudian dianggap sebagai tindak balas yang perlu dicapai untuk reka bentuk bit gerudi baru. Daripada penyiasatan itu, parameter yang paling penting yang memberi kesan kepada prestasi lubang itu adalah sudut penembusan yang sejajar dengan sudut titik. Selain itu juga, interaksi antara sudut heliks dan ketebalan web boleh mengawal prestasi penggerudian. Melalui statistik analisis pengoptimuman, geometri bit gerudi yang optimum dipilih berdasarkan kepada keadaan sudut penembusan 30 ° adalah (25% ketebalan web, 107.0 ° titik sudut, dan 35.0 ° sudut heliks). Reka bentuk bit gerudi optimum baru telah dibina dan diikuti oleh satu set pengesahan melalui kerja-kerja eksperimen yang menghasilkan ralat kurang daripada 10% yang dapat mengesahkan kesahihannya. Dalil sesuatu reka bentuk geometri baru untuk bit gerudi pembedahan yang mengambil kira penggerudian sisihan sehingga 30 ° sudut penembusan akan terus menjadi pemangkin kemajuan kejayaan dalam teknologi biomekanik dan bioperubatan.

ACKNOWLEDGEMENTS

In the name of Allah the Most Gracious and the Most Merciful. I am grateful to Allah S.W.T for awarding me the strength and patience to complete this research. His Mercy and Grace were central to the completion of this work. First and foremost, I would like to express my deepest gratitude to my supervisor, Associate Professor, Dr. Raja Izamshah Bin Raja Abdullah for his guidance, advice, and support. His dedication and commitment encouraged me to strive towards engaging in a deep and sophisticated research and to present it in a clear and systematic manner. Without his suggestions, help, and criticisms, this thesis would not have seen completion. I would also like to thank the lecturers and technicians in Universiti Teknikal Malaysia Melaka especially in the Department of Process, CNC Laboratory Faculty of Manufacturing Engineering for providing me with the knowledge necessary to complete this research. Special thank goes to 'Pakar Perunding Bedah', Dr. Rahmat Haron (Hospital Tuanku Jaafar) and Dr. Zainal Othman (Hospital Kem Terendak) for providing me real practice experiments in the hospital. Thanks also to Kementerian Pendidikan Tinggi for their financial support through the HLP scholarship.

Last but not least, I would like to express profound and sincere gratitude and appreciation to my wife and family for their constant prayer and support throughout this arduous journey riddles with hardship and joy

TABLE OF CONTENTS

LIST OF TABLE

LIST OF FIGURES

LIST OF ABBREVIATIONS

CAD	-	Computer Aided Design
CAM	-	Computer Aided Manufacturing
CMM	-	Coordinate Measuring Machine
RSM	-	Response Surface Methodology
DOE	-	Design of Experiments
ANOVA	-	Analysis of Variance
FEM	-	Finite Element Method
MMCS	-	Metal Matrix Composite
CCD	-	Central Composite Design
HDD	-	Historical Data Design
SEM	-	Scanning Electron Microscope
ORIF	-	Open Reduction Internal Fixation
TCSA	-	Total Cross-Sectional Area
R&D	-	Research and Development

LIST OF SYMBOLS

µm	-	micro meter
°, ° C	-	degree, degree Celcius
Pa, Mpa	-	pascal, mega pascal
mK	-	meter kelvin
g/ cm^3	-	gram per centimetre cube
kg / m^3	-	kilogram per meter cube
mm/ tooth	-	millimetre per tooth
mm/min	-	millimetre per min
mm/rev	-	millimetre per revolution
rpm	-	revolution per minute
%	-	percent
L_c	-	tool -chip contact length
Ø	-	shear angle
Ra	-	arimethic roughness
n	-	number of samples
y, ȳ	-	measured data, average measured data
s^2	-	Variance